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White Paper on Propane Vehicles: Status, Challenges, and Opportunities

A Discussion Paper for Clean Cities Coalitions and Stakeholders to Develop Strategies for the Future

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State of the Technology

Propane is used widely in the petrochemical industry, residential and commercial heating and grilling, the agricultural sector, and industrial applications. However, it can also be used to fuel vehicles. Propane or liquefied petroleum gas (LPG) is commonly referred to around the world as autogas when used as an automotive fuel. Globally, it is the most widely used alternative vehicular fuel. Experiments using propane began around 1910. In 1950, the Chicago Transit Authority ordered 1,000 propane-fueled buses, and Milwaukee converted 270 taxis to run on propane (PERC, 2009a). According to Energy Information Administration (EIA) estimates, roughly 158,000 vehicles operate in the United States using 152 million gasoline-equivalent gallons of propane fuel, while the World LP Gas Association touts more than 13 million vehicles plying the streets worldwide (EIA, 2009a and WLPGA, 2009).

In a naturally occurring state, propane is a three-carbon alkane gas, C_3H_8, at atmospheric pressure, but it can be liquefied if subject to moderate increases in pressure. Liquefied propane has an energy density 270 times greater than gaseous propane, thereby making it practical to store and transport as a liquid (EERE, 2009a). Propane is a by-product of natural gas production and the oil refining process, 60% and 40% respectively (Wang, 1999).

Vehicle Specifications—Propane as an auto fuel has a high octane value and has key properties for spark-ignited internal combustion engines. To operate a vehicle on propane as either a dedicated fuel or dual-fuel (i.e., switching between gasoline and propane) vehicle, only a few modifications to the engine must be made. Until recently, propane vehicles have commonly used a vapor pressure system that was somewhat similar to an old carburetor system, wherein the propane would be vaporized and mixed with combustion air in the intake plenum of the engine. This leads to lower efficiency as a result of breathing losses associated with inducting combustion charge into the cylinder (Gupta, 2009). A newer liquid injection system is capable of injecting propane directly into the cylinder. Such a system will improve breathing efficiency and thereby lead to overall improved engine efficiency (Gupta, 2009). Other systems include the sequential multi-port fuel injection system and a bi-fuel “hybrid” sequential propane injection system.

In the United States, a closed-loop conversion system for after-market conversions is used. This system incorporates an electronic sensor that provides constant feedback to the fuel controller on how it is performing. A complete conversion system includes a fuel controller, valves, actuators, electronics, and software. For conversions to a vapor pressure system, a slight power loss is possible. However, with vehicle modifications of such items as the air/fuel mixture and compression ratios, power can be optimized. Cold start issues are eliminated for vapor pressure systems since the fuel/air mixture is gaseous.

In light-duty propane vehicles, tanks are typically mounted in the trunk, but for medium and heavy-duty vans and trucks, the tank is located under the body of the vehicle. Propane tanks do add weight to the vehicle and can slightly increase the consumption of fuel. On a gallon-to-gallon basis, the energy content of propane is 73% of gasoline (EERE, 2009b).

Safety—Propane is a nontoxic, noncarginogenic, and noncorrosive fuel. It poses no harm to groundwater, surface water, or soil. Since propane is odorless and colorless, an odorant, ethyl mercaptan, is added for leak detection. Propane vehicles and their respective fueling systems are designed to perform safely during both normal operations and crash situations. A pressure release device (PRD) is designed to release propane gas if pressure rises in the tank beyond safe levels.

Recently, there has been some concern regarding fuel tanks being overfilled and, consequently, potentially releasing emissions from faulty pressure relief valves. The U.S. Department of Energy's (DOE's) Clean Cities Program conducted tests on 105 vehicles being fueled. According to the Alternative Fuels and Advanced Vehicles Data Center's (AFDC's) Propane Tank Overfill Safety Advisory Technology Bulletin, nearly 16% had overfill prevention devices (OPD) that failed to activate, and therefore, did not stop fueling at the necessary level. Other conditions can cause overfilling as well, such as rising ambient air temperatures (i.e., if a tank is overfilled during a cool time of day and sits without being used, hot temperatures later in the day may cause the expansion of the fuel and could potentially lead to a fuel release or leak through the PRD). The study concluded that while this number is significant, tanks are equipped with PRDs to ensure safe pressure levels, and no incidents have been reported. Therefore, the following steps were recommended: (1) inspection of the OPDs in vehicle fleets and an ongoing inspection process; (2) training and education of propane vehicle users to make them aware of the potential to overfill and the potential causes; and (3) implementation of standard maintenance and inspection by industry groups. DOE is working in close coordination with the National Propane Gas Association Technology Standards and Safety Committee, the Propane Education and Research Council (PERC), and the Underwriters Laboratory to develop training and outreach strategies (EERE, 2009c).

Infrastructure—In regard to propane infrastructure, the dispensing time is similar to that for gasoline or diesel fills at about 10–12 gallons per minute. The storage tank of a propane station connects to the dispenser that fills the vehicle's on-board storage cylinder. Propane is stored and handled as a liquid at the fuel dispenser. New nozzles and valves have been introduced, thereby preventing volatile organic compound (VOC) emissions from escaping from refueling stations (Hyland, 2007).

***Fuel Quality*—**Three grades of propane may be used as a motor fuel in the United States, with HD-5 being the most widely used. For optimal performance, the fuel quality of propane should meet HD-5 requirements and contain at least 90% propane, no more than 5% propylene, and no more than 2.5% butanes (or heavier). HD-5 has superior antiknock characteristics (i.e., a high octane rating [110 RON/100 MON]), which can be taken advantage of through the use of turbocharging. Propane that meets the California Code of Regulations is commonly referred to as "HD-10," although this is not an official specification. HD-10 contains a minimum of 85% propane, a maximum of 10% propylene, 5% butanes, 2.5% butenes, and 0.5% pentenes (or heavier), and limited sulfur content (80 ppm vs. 123 ppm for HD-5). The third type of propane is commercial-grade LPG. It has no limit to propylene and can be used in forklift engines (Ross, 2007). In some areas of the country, fuel standards were not being met by producers. However, this appears no longer to be of concern, since producers have ensured that these specifications are met on a more rigorous basis (Donaldson, 2009).

Current Market Status

***World and U.S. Transportation LPG Usage, Availability, and Pricing*—**Autogas is Europe's leading alternative fuel, with 7 million vehicles, or 3% of the passenger fleet, using it. European countries using autogas the most are Turkey (at 25%) and Poland (at 15%). Elsewhere throughout the world, 6 million more vehicles (cars) use LPG. The leading countries in descending order of numbers of vehicles and dispensing sites, respectively, are:

	Vehicles	Dispensing Sites
South Korea	2.2 million	1,500
Poland	2.1 million	2,450
Australia	620,000	3,200
Russia	600,000	2,000
Mexico	550,000	2,500
India	500,000	550
Japan	292,300	1,900
The Netherlands	270,000	1,900

In South Korea, the autogas vehicle fleet grew from 400,000 in 1997 to 2.2 million in 2008. Ford and General Motors offer propane vehicles in Europe and Australia (ELPGA, 2009).

In contrast, transportation use of propane is far lower in the United States. As previously noted, EIA's Annual Energy Review 2008 estimates that 158,000 propane vehicles operate in the United States, with a total transportation consumption of 152 million propane gallons annually. Less recent (but still relevant) data indicate that this was about 3% of U.S. annual propane consumption in 2006 and equal to only about 11 days of annual U.S. propane supplies (EIA,2009b). The United States has 2,470 propane fueling stations as of August 27, 2009, according to the U.S. DOE's AFDC (See Figure 1 below), with Texas (570 stations), California (206 stations) and Alabama (161 stations) having more than 100 (EERE, 2009d).

The four states that consume the most propane transportation fuel are North Carolina (17%), California (11.5%), Michigan (6.9%), and Texas (6.4%). Texas is the largest state consumer of LPG for all usage sectors combined. However, it is also part of a national trend away from propane and toward other alternative fuels and vehicle technologies, such as ethanol, biodiesel, and hybrids. According to the Texas Comptroller of Public Accounts (TCPA), in 2006 Texas propane vehicles represented 73% of the state's fleet of 7,400 vehicles using alternative fuels (TCPA, 2009). The Texas Department of Transportation (DOT), which had the largest component of the state fleet of propane vehicles, had a precipitous decrease in propane vehicles. In 2001, the Texas DOT had 4,677 LPG vehicles; by 2006, it had 2,938, a drop of 37%. Along with the rest of the state's fleets and many other state fleets nationwide, they were switching to vehicles using other alternative fuels. Contributing to this decline, moreover, is the Texas DOT's discomfort with after-market conversions of gasoline-powered vehicles to propane and the limited number of public propane fueling stations, which requires the Texas DOT to maintain their own fueling stations (TCPA, 2009). Note that the DOE data cited earlier indicated that Texas, with its 570 stations in August 2009, has significantly more stations than the next most serviced state, California, which has 206 stations (EERE, 2009d). This trend has occurred even though Texas produced 36% of the nation's propane in 2002 (TCPA, 2009).

The TCPA report indicating that Texas is still the fourth largest consumer of transportation propane, even though that use is declining, explains why it is still widely used in Texas as compared with other states. When a major propane supply source or pipeline is not available, customers farthest from such sources generally must pay higher propane prices because of the high cost to transport propane. The transportation sector's position as one of the smallest users of propane places it in a highly unfavorable position for buying this fuel. Propane use is dominated by the petrochemical industry (49%), residential and commercial users (40%), farm users (5%), and industrial users (3%), who all have more buying power. This advantage is especially true for the petrochemical industry, which is primarily located near major supply sources that deliver their propane by pipeline. This delivery system allows for a lower unit cost (cents per gallon) for these firms (and Texas transportation users) than for other propane users (EIA, 2008).

Further, propane prices spike, especially in the peak heating season during early and/or especially cold winters, severely reduce supply and create shortages. Such spikes exacerbate the price disadvantage of propane in comparison with gasoline that generally exists in all regions. According to the U.S. DOE Clean Cities Price Report, in July 2009, the average price of propane was $0.99 per gasoline gallon equivalent (GGE) higher than gasoline and $1.16 per GGE higher than diesel (EEREe, 2009). See Table 1 below for a recent history of average monthly prices for the three fuels.

Table 1: Monthly Average Price of Gasoline, Diesel, and Propane (per GGE)

	Gasoline	Diesel	Propane
July 2009	$2.44	$2.27	$3.43
April 2009	$2.02	$2.26	$3.56
January 2009	$1.86	$2.19	$3.77
October 2008	$3.04	$3.27	$4.67
July 2008	$3.91	$4.22	$4.34
April 2008	$3.43	$3.71	$4.36
January 2008	$2.99	$3.05	$4.31
July 2007	$3.04	$2.65	$3.57
March 2007	$2.30	$2.35	$3.62
June 2006	$2.84	$2.67	$2.88
February 2006	$2.23	$2.48	$2.74

Source: EERE, 2009e, *Clean Cities Alternative Fuel Price Report*

Current Vehicle Availability, Pricing, and Niche Markets—In the late-1990s, the original equipment manufacturers (OEMs) offered three propane vehicles, peaking to five models in 1999, 2001, and 2002; soon after that, no OEMs offered any vehicles (EERE, 2009f). This left fleet users and other consumers interested in more product choices. Several years ago, PERC and its members developed and followed a market strategy of working with OEMs and other manufacturers to develop OEM products or Tier II OEM products with a master dealer program, thereby establishing service, maintenance, and warranty support programs for dealers, fleet customers, and consumers. As a result of this effort, the market situation has changed to offer greater options to the fleet consumer and a continued steady increase in model availability through model year (MY) 2010.
One example of industry partnerships is Roush Industries, Ford Motor Company, and CleanFUEL USA. These organizations collaborated to develop a Liquid Propane Injection (LPI™) system that allows the Roush F-150 5.4-L V8 engine to run on propane. According to the manufacturers, this system results in more complete combustion, improved fuel economy, and a 300-mile range. At the end of 2009, Roush will also be offering the F-250 and F-350 using the LPI™ system (Roush, 2009). In the fourth quarter of 2009, the Ford E-250 van will be offered as a propane option, with the E-150 and E-350 following in 2010 (Feehan, 2009a). All are expected to be certified to U.S. Environmental Protection Agency (EPA) and California Air Resources Board (CARB) 2010 emission standards.

The LPI™ system was also chosen by Blue Bird Bus Corporation for its new 2008 Blue Bird Propane Vision school bus, using the General Motors (GM) 8.1-L engine. The LPI™ 8.1-L platform is currently available in GM cab chassis configurations from 17,500- to 33,500-lb GVW. GM is slated to end the 8.1-L engine platform by the end of 2009. In the case of propane school bus options, the propane vehicle industry and Blue Bird are working on a bridge strategy to find other partners to continue this important model option (Feehan, 2009b).

In addition, CleanFUEL USA is in the process of getting the GM 6.0-L engine, with an improved LPI™ system, certified to 2010 standards. This engine will be used for cab van cutaways and a variety of applications, such as shuttles (Donaldson, 2009).

In regard to heavy-duty propane engine manufacturers, through MY 2009, Cummins Westport, Inc., manufactured a 5.9-L, in-line six-cylinder, spark-ignited-lean burn engine. However, according to Cummins Westport, Inc., this product-line will end (Exel, 2009). While still under consideration by the PERC Board, PERC is seriously considering funding the development and certification of the Navistar International DT 466 diesel platform in a propane version with Emission Solutions, Inc. If the proposed plan is approved by PERC in October 2009, engine development and certification will require one year (Moore, 2009).

Within the coming year, small-volume manufactures, such as IMPCO Technologies, Inc., are slated to offer new bi-fuel products for police and taxicab fleets and sedan and limousine applications that meet 2010 standards (Feehan, 2009a). Some companies have formed marketing cooperatives, such as Alliance AutoGas, to offer conversion kits for existing fleets of vehicles, such as taxis and police vehicles. This model relies on propane marketers and includes having certified conversion centers that install the Prins VSI (vapor sequential injection) systems (EPA/CARB certified for a variety of MY 2006–2009 vehicles) and provide on-site refueling, training, and maintenance support (Weidie, 2009).

Also, the off-road forklift market has OEM product offerings in propane. Kawasaki Motors has a lower nitrogen oxides (NO_x) option for non-road propane engines that yields at least a 40% improvement over mandatory standards and meets the EPA's Blue Sky requirements. This system was also developed in partnership with PERC (Pack, 2008). In addition, there are now eight manufacturers of propane zero-turn radius mowers. Table 2 below provides a list of currently available on-road propane vehicles, engines, and systems and the various manufacturers. This information is based on the *2009/2010 AFV Buyers Guide* (AFVi, 2009).

Table 2: On-Road Propane Vehicles, Engines, and Systems

Manufacturer	Engine Type	Applications
Roush	F-150, 250, and 350 CleanFUEL USA liquid propane injection system – 5.4-L V8 engine	Multiple fleet and personal uses
Foton America – LD 1000	Foton Loval, 140 hp	Class 3 truck delivery
Kalmar Ottawa 4x2 LPG	5.9 L, 195 hp	Class 4 truck delivery
Krystal Koach – Ford F-550	6.8-L V-10 gas or 6.4-L V-8 diesel	Class 5 shuttle van
E-bus Hybrid-Electric Transit Bus and Electric Trolley	Single string of 50 100-AH SAFT nickel-cadmium liquid cooled modules	Class 6 transit buses and trolleys
Krystal Koach – Chevrolet KK36	8.1-L V-8 gas/6.6-L diesel	Class 6 shuttle bus
ElDorado National-Passport	Vortec 8.1-L gasoline or 6.6-L Duramax diesel	Class 6 shuttle bus
Trolley Enterprises		Class 6 trolley
Blue Bird Corp – Vision	GM 8.1 L with CleanFUEL USA LPI™ system	Conventional Type C/Class 7 fully integrated and purpose-built OEM school bus; ends 2009, but working to find a replacement for the GM 8.1-L engine.
ElDorado National – EZ Rider II 30/35	Cummins	Class 7 transit bus
TYMCO – Model 600		Class 7 work truck
ElDorado National – XHF 29/33/35	Cummins	Class 8 transit bus
Technocarb Equipment (2004) Ltd.	Dedicated and Bi-fuel Economy Sequential Injection Package for 3–8 cylinder engine applications on multiple Ford models for taxis, police, and other light-duty applications, and industrial equipment	Multiple fleet and personal uses
IMPCO Technologies	Vapor sequential fuel injection system conversion kit for internal combustion engines one-half to 5,000 hp	Low-volume manufacturing for bi-fuel 2008/09 Chevrolet Silverado, Express, and G-Van Cutaway; 2008 GMC Savana; and 2008/09 GMC Sierra
Baytech Corporation	Dedicated conversions: for 2009 8.1-L GMC/Chevy C4500/C5500 truck and shuttle bus; 8.1-L Workhorse Custom Chassis W62; 6.0-L GMC/Chevy W4500 and Isuzu NPR HD; 6.0-L Workhorse Custom Chassis W42 (over 14k-lb GVWR)	Low-volume manufacturing for trucks, shuttle buses, and workhorses
Campbell-Parnell	Dedicated conversion	Conversions of various Ford, GM, Isuzu, and Dodge models
American Alternative Fuel	Bi-fuel conversion, vapor sequential injection systems	Pick-up trucks, vans, utility vehicles, over-the-road vehicles, emergency vehicles, and land-side passenger vehicles, among others.
Cummins Westport B LPG Plus 195	5.9-L, in-line 6 cylinder, spark ignited-lean burn, 195 hp	Multiple medium-duty and heavy-duty applications (production will end in 2009)
Emission Solutions, Inc.	Potential product under consideration	Multiple medium-duty and heavy-duty applications
Foton America – LD1000	Foton Loval engine, 140 hp	Work truck

Source: *2009/2010 AFV Buyers' Guide*

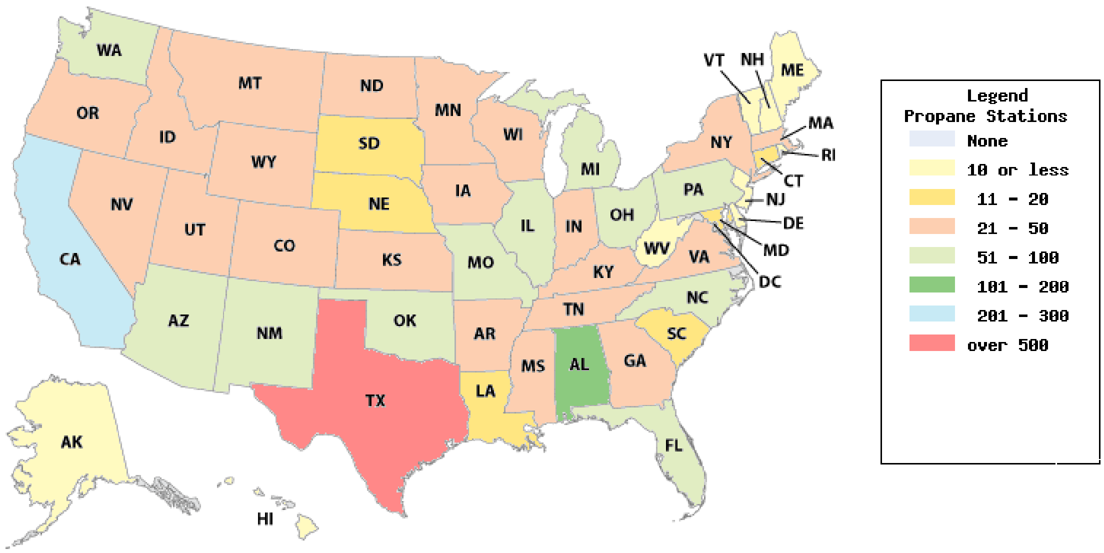
With regards to the price of propane vehicles, according to one conversion kit manufacturer, Technocarb, the costs of conversions for their economy sequential injection package are the following: $1,309 for a 3- or 4-cylinder component, $1,579 for a 5- or 6-cylinder component, and $1,689 for an 8-cylinder component (Technocarb, 2009). The Roush Ford F-150 LPI™ conversion kit for 2007–2008 with the in-bed 59-gallon fuel tank option is $7,795, while the kit for an F-250 or F-350 truck, MY 2009–2010, is $9,995 (Roush, 2009). The propane Blue Bird bus is roughly $13,787 more than a similar conventional model (Bogart, 2009a).

***Propane Niche Markets*—**With the possibility of new bi-fuel light-duty vehicles meeting EPA and CARB 2010 standards, two target markets are considered prime candidates by PERC: taxi and police fleets. According to the U.S. Department of Transportation’s Bureau of Transportation Statistics (BTS), there were, as of 2005, 162,000 taxi vehicles and 412,000 police vehicles in the United States (BTS, 2009a)). Police vehicles are replaced at different times/mileages depending on the department, although one source has the target range estimated at 89,000–95,000 miles (Schmechel, 2009). One manufacturer, Carbon Motors Corporation, sees high potential in sales, with 75,000 police cars being replaced annually (Indy.com, 2009).

School buses are another key market for the propane industry. The number of vehicles in 2006 was estimated to be 505,000, according to the Union of Concerned Scientists (UCS, 2006). In the recently released ICF International (ICFI) report, *2009 Propane Market Outlook*, Blue Bird was hoping to sell 14,200 units of LPG by 2013. According to the ICFI report, there are currently 2,000 LPG school buses (Sloan and Meyer, 2009). Propane has also found success in the paratransit bus market. In 2006, according to the American Public Transit Association, 3.7 million gallons of LPG were consumed by paratransit buses (APTA, 2009). A significant opportunity exists for this market segment should the 6.1-L engine be certified.

Propane Stations and Cost**—**As mentioned above, according to DOE's Alternative Fuels and Advanced Vehicles Data Center, there are 2,470 public and private propane stations in the United States. See www.afdc.energy.gov/afdc/fuels/stations.html for updates on these statistics (EERE, 2009d).

Figure 1: The Number of Propane Stations by State



One manufacturer, CleanFUEL USA, has estimated the average cost for a propane fueling station, with various tank sizes, on the basis of the three scenarios described below: (Bogart, 2009b).

1. **Base Model Propane Fueling Dispenser**
   Non-electronic meter, 0.5-hp pump, low-profile basic cabinet that is very similar to the forklift or gas station dispensers typically used for filling RVs and BBQ bottles (not recommended for motor fuel applications but will work in most cases).

   Estimated Costs Installed—Based on Storage Tank Size:

   a. 500-gallon tank with a turnkey dispenser skid system: ~$25,000
   b. 1,000-gallon tank with a turnkey dispenser skid system: ~$33,000
   c. 2,000-gallon tank with a turnkey dispenser skid system: ~$48,000

2. **Propane-Autogas Fueling Station—Designed for Fleet Motor Fuel Applications**
   Fully integrated electronic dispenser with two wire interface capabilities for most of the major proprietary fuel management network cards, such as Fuel Man,

Petro-Vend, and Gas Boy; records Word- or Excel-based fueling transaction data:

a. 500-gallon tank with a turnkey dispenser skid system: ~$37,000
b. 1,000-gallon tank with a turnkey dispenser skid system: ~$45,000
c. 2,000-gallon tank with a turnkey dispenser skid system: ~$60,000
d. 15,000-gallon tank with two dispensers on the fueling island: ~$130,000
e. 15,000-gallon tank with four dispensers on the fueling island: ~$155,000

3. **Propane-Autogas Retail Fueling Station—Also Designed for Large Fleet Applications**
Fully functional electronic autogas dispenser with retail EPOS credit card transactions—designed for retail and large fleet applications; seamless retail fueling dispenser system available in both Gilbarco and Dresser-Wayne models:

a. 1,000-gallon tank with a turnkey EPOS dispenser skid system: ~$92,000
b. 2,000-gallon tank with a turnkey EPOS dispenser skid system: ~$102,000
c. 15,000-gallon tank with two EPOS dispensers on the fueling island: ~$150,000
d. 15,000-gallon tank with four EPOS dispensers on the fueling island: ~$175,000

World and United States-Canada Propane Supply Trends—Supplies of LPG, the form of propane gas created through the application of moderate pressure, come primarily from natural gas processing, which accounts for about 60% of total worldwide production. Oil refineries accounted for nearly all of the remaining production, with other sources accounting for less than 0.5%.

The world supply of LPG grew steadily during the 2000–2008 period, from about 200 million tons in 2000 (about 6.2 million bbl/day) to 239 million tons (7.7 million bbl/day) in 2008. Prices had also been steadily rising for most of the decade. During the summer of 2008, LPG prices had approached all-time highs, but since then the global recession depressed natural gas and oil prices and, along with them, the price of their by-product, LPG (Hart, 2009).

Despite the issue of rising prices, a major international energy consulting firm, Purvin and Gurtz, expects world LPG supplies to reach 20 million tons (about 8.4 bbl/day) by 2012 (Purvin and Gurtz, 2009). Through 2008, the United States and Canada remained the world’s largest producers of LPG, together accounting for about 24% of supply. Production in this region has declined slightly between 2000 and 2008, from 59 million tons to 57.7 tons, because of the decline in conventional natural gas production, which constitutes 61% of the region’s production. Conventional natural gas production is still declining, but it has been offset somewhat by greater production of unconventional natural gas, including tight sands gas in the Rockies and the Barnett shale formation in the Fort Worth Basin in Texas (*Hart*, 2009 and Airhart, undated). Overall, LPG production in the region is expected to remain at 58–59 million tons through 2012 (Purvin and Gurtz, 2009).

Available Federal and State Incentives

Type of Incentive	Federal Law	Provision
Fuel	Emergency Economic Stabilization Act/Energy Improvement and Extension Act of 2008, P.L. 110-343 (10/03/08)	Section 204 amends the expiration date for the existing alternative fuel excise tax credit from September 30, 2009, through December 31, 2009.
	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users, P.L. 109-59 (8/10/05) (SAFETEA LU)	An excise tax credit is available for an alternative fuel that is sold for use or used as a fuel to operate a motor vehicle. The credit is $0.50 per gge of CNG and $0.50 per liquid gallon of liquefied petroleum gas, liquefied natural gas, and liquefied hydrogen. The entity eligible for the credit is the one liable for reporting and paying the federal excise tax on the fuel. The tax credit is also available to nonprofit tax-exempt entities that fuel on site. The excise tax credit, paid from the General Revenue Fund, is partially offset by an increase in the motor fuel excise tax rate for LPG that is now on parity with that for other motor fuels. The sale of propane for use in forklifts is exempt from the federal excise tax on motor fuels. In providing further guidance regarding the legislation, the Internal Revenue Service (IRS) made it clear that forklifts fit the definition of an off-highway business motor vehicle and, therefore, the fuel used in a forklift is eligible for the $0.50 cent/gallon credit. Moreover, the IRS indicated that in this instance it is the end user, namely the forklift operator, who is entitled to apply for the credit, rather than the propane marketer.
Vehicle	Energy Policy Act of 2005, P.L. 109-58 (8/8/05)	A "qualified alternative fuel motor vehicle" tax credit is available for the purchase of a new, dedicated, or repowered alternative fuel vehicle. It is for 50% of the incremental cost of the vehicle, plus an additional 30% if the vehicle meets certain tighter emission standards. These credits range from $2,500 to $32,000, depending on the size of the vehicle. The credit is effective on purchases made after December 31, 2005, and it expires on December 31, 2010. The vehicle must be acquired for use or lease by the taxpayer claiming the credit. Furthermore: (a) The credit is available only to the original purchaser of a qualifying vehicle. If a qualifying vehicle is leased to a consumer, the leasing company may claim the credit. (b) For qualifying vehicles used by a tax-exempt entity, the person who sold the qualifying vehicle to the person or entity is eligible to claim the credit, but only if the seller clearly discloses in a document to the tax-exempt entity the amount of credit. The seller may pass along any savings of the tax credit but is not required to do so. The IRS does not set limits on the amount of credits claimed by any one entity.
Infrastructure	American Recovery and Reinvestment Act of 2009, P.L. 111-5 (2/17/09)	This Act increases the value of the credit (from EPACT 2005) for the purchase of equipment that is used to store and dispense qualified alternative fuels and is placed in service during 2009 and 2010. The credit for these years is

		$50,000 or 50% of the cost, whichever is smaller, for business property and $2,000 or 50% of the cost, whichever is smaller, for home refueling.
	Emergency Economic Stabilization Act/Energy Improvement and Extension Act of 2008, P.L. 110-343 (10/3/08)	Section 207 amends the existing alternative fuel infrastructure tax credit through December 31, 2010.
	Energy Policy Act of 2005, P.L. 109-58 (8/8/05)	An income tax credit is available. It is equal to 30% of the cost of propane refueling equipment—up to $30,000 in the case of large stations. The credit is effective on purchases placed in service after December 31, 2005, and it expires on December 31, 2010 (see above for modifications).

Sources: http://www.afdc.energy.gov/afdc/incentives_laws.html (EERE, 2009g); http://www.propanecouncil.org/uploadedFiles/IRS_Forklift_Fuel_Tax_Credit.pdf (PERC, 2009b).

Model State Example—According to Stacy Noblet of the Clean Cities Technical Response Center, Texas is the only state that offers a *specific* propane vehicle incentive program. Through the Railroad Commission of Texas's Alternative Fuels Research and Education Division, the Low Emissions Propane Equipment Initiative is offered, which gives buyers the opportunity to replace aging medium-duty diesel school bus or delivery vehicles with LPG vehicles that meet or exceed EPA emission standards. The incentive is dependent upon the calculated reduction in emissions. This program also offers incentives to buyers who want to replace aging internal combustion engine forklifts with new propane forklifts that meet or exceed 2008 EPA emission standards (Noblet, 2009).

Emission Benefits

Because of regional differences in fuel composition and engine configurations, potential "in-use" emission reductions from the deployment of propane vehicles can vary. (Certification test results are based on standard fuels, which are generally not the same as used in the field). The EPA examined the benefits of propane, based on its inherent chemical properties with respect to gasoline, used in a properly calibrated vehicle. It was reported that propane has the potential to have lower toxic, carbon monoxide (CO), and nonmethane hydrocarbon (NMHC) emissions. However, emissions varied depending on whether an engine was calibrated to run rich or lean. When running rich, higher NMHC and CO emissions, but lower NO_x, were observed; when running lean, lower NMHC and CO emissions, but slightly higher NO_x, were observed (EPA, 2002). Argonne researchers examined the fuel cycle energy use and emissions of transportation fuels produced from natural gas. In their report, they projected the tailpipe emission changes of LPG vehicles compared with Tier 2 gasoline vehicles. They estimated no change in exhaust VOCs or NO_x, a 90–95% reduction in evaporative VOCs, a 20–40% reduction in CO, and an 80% reduction in exhaust coarse particulate matter (PM_{10}) (Wang and Huang, 1999). Unfortunately, without recent light-duty vehicle testing, the exact benefits of LPG vehicles compared with gasoline counterparts are unclear.
Recent engine dynamometer tests from the EPA show similar emissions for propane engines compared with compressed natural gas (CNG) engines (specifically, the Cummins B LPG Plus and the B Gas Plus). However, it remains to be seen if LPG engines will be able to meet the strict 2010 EPA NO_x standards.

Petroleum and Carbon Benefits

We estimated the petroleum and carbon benefits of propane vehicles using Argonne's Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model. The model estimates the full fuel-cycle energy use and emissions for alternative fuels and advanced vehicle systems for light-duty vehicles. However, it can be used to approximate larger (i.e., medium- and heavy-duty) vehicles. When LPG vehicles are examined, a key assumption is whether the feedstock is petroleum or natural gas. GREET uses the default assumption that currently 60% of LPG in the United States comes from natural gas and that percentage could increase in the near-term. Obviously, while petroleum-based LPG does not reduce petroleum use, it does diversify fuel use by reducing the conventional petroleum transportation fuels (i.e., gasoline and diesel).

On a miles-per-gasoline-gallon equivalent (mpgge) basis, GREET presently assumes that a dedicated light-duty LPG vehicle will have the same fuel economy as a comparable conventional gasoline internal combustion engine vehicle (ICEV). However, with regard to heavy-duty vehicles, we were provided fuel economy data from the Alvin Independent School District (ISD) for 12 vapor injection LPG buses, 12 liquid injection LPG buses, and 12 diesel buses, all with similar passenger loads. The Alvin ISD, which covers communities just south of Houston, has operated propane-fueled school buses since 1980 and, as of 2009, has 82 propane buses out of a fleet of 160. However, they stopped purchasing propane buses in 2002 and only just this year acquired new ones, which use liquid injection systems (Ralph, 2009).

The data for the vapor injection LPG buses, which were for the most recent year (the same for diesel data), show a 40% lower diesel-equivalent fuel economy for these LPG buses as compared with the diesel buses. However, the new liquid injection buses, which have been running for only a few months, show a 40% improvement in diesel-equivalent fuel economy as compared with the diesel buses. This difference in vapor and liquid injection is quite dramatic, though since this was not a scientific study, these results and the fuel economy of liquid injection systems should be further examined. The comparison is not an apples-to-apples comparison because the vapor injection LPG buses were acquired before 2002, and the diesels are likely older model years as well, though such details are unclear. In addition, we do not have the details about the routes taken by each bus; therefore, factors outside the actual vehicle efficiency could be influencing these values.

In 2010, on the basis of default GREET assumptions, a 23-mpgge light-duty gasoline ICEV's full fuel-cycle fossil-energy use would be 5,928 Btu/mi, its petroleum energy use would be 5,274 Btu/mi, and its greenhouse gas (GHG) emissions would be 478 g/mi. The results for comparable vehicles using natural-gas-based LPG and petroleum-based LPG are shown in Table 3. The natural-gas-based LPG resulted in significant (about 99%) petroleum displacement and modest reductions (about 18%) in GHG emissions. The petroleum-based LPG vehicle had very similar petroleum use to a gasoline vehicle, but it had GHG reductions (about 15%) similar to natural-gas-based LPG.

Table 3: Energy Use and GHG Emissions of Gasoline and LPG Vehicles

Vehicle	Fossil Energy (Btu/mi)	Petroleum Energy (Btu/mi)	GHG Emissions (g/mi)
Gasoline Light-Duty Vehicle (LDV)	5,928	5,274	478
LPG (NG) LDV	5,453	55	393
LPG (Petroleum) LDV	5,539	5,170	404

If liquid injection systems show similar fuel economy improvements, as seen in the limited school bus testing, the carbon benefits of LPG could be greater than in the light-duty vehicle example above. This is a major factor in determining the carbon footprint of LPG vehicles. Therefore, it would be good to see more concrete details on the fuel efficiency of new LPG systems as compared with conventional vehicles.

Current Available Resources, Activities, and Strategies by Clean Cities, Industry, or Other Government Agencies

PERC Research and Deployment Initiatives— In 2007, with propane vehicle options declining, PERC members agreed to invest more than $5.1 million to facilitate the development of new propane technologies, with 21% of this investment targeted to on-road engine research and 2% for off-road vehicles. The following year, PERC raised its research and development budget to more than $7.0 million. PERC's goal is to conduct research with a commercialization focus to advance propane technology and products. PERC intends to support that effort through communications initiatives to expand propane's position as a leading alternative fuel and to increase sales of propane for on-road, off-road, and stationary engines (Pack, 2008).

In the 2008–2012 Strategic Plan of PERC, the objectives include: (1) enhance propane's position in the forklift market; (2) pursue research to develop platforms, engines, vehicles, and certified fuel systems; (3) improve the fuel market for engines through internal and external marketing and communication mechanisms; (4) increase knowledge by developing maintenance and training programs; (5) develop programs that are easily replicated across the country in multiple markets; (6) facilitate cooperative interaction among market sectors; (7) collect data to identify potential market opportunities and emerging needs to benchmark propane's engine fuel market share, and to measure trends in fleets' and other consumers' attitudes toward propane vehicles and engines; (8) emphasize the economical and environmental benefits of propane as an engine fuel; and (9) educate target markets on how propane can contain costs and meet increasingly stringent environmental regulations (PERC, 2009c).

Research funding is made possible because of the Propane Education and Research Act of 1996, which allows for no greater than one-tenth of 1 cent per gallon of odorized propane to be allocated toward PERC activities (PERC, 2009d). This funding led to the development and commercialization of an OEM Propane School Bus—the Blue Bird Vision school bus (PERC, Docket 11943) and the development of the propane-powered Roush Ford F-150 (PERC, Docket 11942). PERC has also funded market research for fleet managers. The data collected will help to determine how propane can best meet and exceed fleet managers' needs as an engine fuel (PERC, Docket 12465). PERC has invested in other engine products, including the performance evaluation of propane injection for diesel engines to optimize engine performance and reduce emissions. Also, PERC has funded the engine emissions certification and durability development of the GM 6.0-L engine designed for a dedicated LPI™ system (PERC, Dockets 12195 and 12413). The research and commercialization of an EPA-Certified Zero Turn Radius Mower was also another priority of PERC, which is striving to develop engines that run about 40% cleaner than engines that meet the mandatory emission standards, with a 3,000 unit production goal by year three (PERC, Docket 12466). In addition to research and development, PERC has also sponsored "Road Shows" to showcase product lines. In partnership with the DOE's Clean Cities Program and the Maryland Energy Administration, PERC has been offering 20 Webinars on a monthly basis to retail marketers and Clean Cities managers.

PERC is planning to announce an *Adoption Market Strategy* for 20 key cities within the United States. This is a joint partnership with ConocoPhillips to build propane infrastructure at existing ConocoPhillips stations and to market the fuel and product line to fleets in the surrounding areas. The goal will be to link these cities to develop corridors across the country (Feehan, 2009a).

Clean Cities—DOE's Clean Cities has been a key partner with industry. The program provides grant opportunities to increase the propane vehicle market, by both buying down the incremental cost of vehicles and paying for the associated costs of infrastructure. From 1999 to 2006, Clean Cities has awarded more than $3.2 million toward these activities. Clean Cities Coalitions are also involved in numerous outreach activities in their communities to encourage fleets to switch to propane. In 2008, 86 of 87 Clean Cities coalitions reported 22,300 LPG vehicles from a total inventory of 632,000 alternative fuel vehicles (AFVs) operating in their communities. While only 4% of the total inventory, two-thirds of these LPG vehicles were reported to be heavy-duty, resulting in 13% of the total AFV fuel displacement, which was second to CNG vehicles. For non-road vehicles, roughly 2,333 vehicles were reported, and propane was clearly the fuel of choice, with 84% using this fuel (Johnson and Bergeron, 2009).

Other Agencies**—**Additional support for propane vehicles has come primarily from the U.S. DOT and the EPA. Within the U.S. DOT, the Federal Highway Administration has historically funded propane projects in nonattainment areas through the Congestion Mitigation Air Quality Program. To obtain this funding, propane vehicle projects must be first placed in a State Implementation Plan. Local governing boards then determine whether a project is ultimately funded. The EPA has also funded competitive grant programs through the SmartWay umbrella. In particular, the Clean School Bus Program has funded natural gas and propane buses. However, funds have gone primarily to clean diesel technology.

Barriers in the Marketplace and Technology Needs

Product Availability and Conversion Technology Process and Cost**—**As with natural gas vehicles, but more pronounced within the propane vehicle industry, a lack of product availability is a major impediment, although this situation has been improving. The OEMs ceased production of propane light-duty vehicles and trucks after 2002. Furthermore, new EPA and CARB emission regulations have limited the number of compliant conversion kits and made it cost prohibitive for some small-volume manufacturers to compete. Beginning in 1997, propane vehicle conversions were impacted by the EPA's addendum to Memorandum 1A, which led to sharp decreases in the number of vehicle conversions. Additionally, many of the existing propane fleet vehicles from the 1990s have been retired, and this has led to a further erosion of propane vehicles on the roadways. With school buses being a prime candidate for propane, the pullout by GM in manufacturing the 8.1-L LPI™ engine will slow progress in this key niche market. As previously mentioned, Cummins Westport, Inc., will end its LPG engine line in 2009.

However, as noted earlier, the propane industry has initiated several partnerships that will increase product choices in MY 2010. Roush will offer F-250 and F-350 conversions, and CleanFUEL USA is working on certification of the 6.1-engine platform. Small-volume manufacturers are expected to have conversion kits certified to light-duty EPA and CARB 2010 standards, thereby offering police and taxi fleets new choices. Other companies have certified products available to convert existing police and taxi fleet vehicles to propane.

Lack of Emission Data**—**In addition to increasing the number of vehicle options, the lack of recent testing and evaluation data of on-road propane vehicles is problematic. As mentioned in the Alvin ISD case study, the LPI™ system was showing significant potential gains in efficiency over the older vapor system and diesels. Drawing final conclusions would require more data points and a firm testing procedure. This type of study could be quite beneficial to Clean Cities coalitions and fleet managers and help to influence the decision-making process should the data be more conclusive.

Lack of Interest or Knowledge to Promote Propane Vehicles by Small-Scale Propane Fuel Distributors**—**The propane industry has been criticized for not promoting propane as a vehicular fuel in a cohesive fashion. Many small-scale distributors prefer to deal strictly with retail customers and fear that an increased demand for propane would raise prices. Some distributors are unaware that propane can be used as a vehicular fuel, or they might be aware but not knowledgeable about the benefits, product choices, and so forth. In addition, some states or insurance companies require certification to dispense LPG as a vehicular fuel. This situation may also prevent distributors from entering the market.

Volatile Organic Compound Emission Leaks in Refueling Infrastructure**—**In the 2007 California Alternative Fuels Energy Plan, one of the immediate actions listed for the propane industry was to facilitate and resolve VOC emission leaks during the fuel transfer process at 700–900 existing LPG stations. Five years ago, as a proactive step, the

Western Propane Gas Association Low Emission Equipment Rebate Program was instituted to allocate funding to remove existing equipment, such as valves and nozzles, and replace it with new, low-emission equipment. A closer examination may be needed to determine if this is a serious issue for more states and existing infrastructure. (The new dispensing equipment that is currently installed uses low-emission valves and nozzles.) Considering that 10 states follow CARB emission standards and the possibility of future EPA regulations, it may be prudent to implement a program similar to that of the Western Propane Gas Association.

***Adequate Number of Refueling Stations*—**While the AFDC reports 2,470 propane stations in the United States, this number pales in comparison to the number of gasoline stations available to the public, at roughly 164,000 in 2007 (Davis et al., 2009). As previously noted, PERC is trying to address this issue with the *Market Adoption Strategy*, which will link cities together in key markets.

***Price of Fuel*—**If a fleet has not secured a long-term contract for a lower price of propane, then the cost of propane fuel could be a deterrent to adoption. The higher price of propane would also be a disincentive to the general public.

Opportunities in the Marketplace

Propane Supply and Price of Fuel—The good news for transportation propane use in the United States is that supply should not be a problem in the near future, neither worldwide nor in the United States and Canada, because of ample natural gas and petroleum processing. However, propane users also must compete for supply with petrochemical, residential, commercial, farm, and industrial users. As such, propane users are highly vulnerable to price spikes, especially during early and unusually cold winters, unless they are locked in a yearly fixed price. However, in late 2007, such a price lock-in would have resulted in the loss of all benefits of the oil (and its derivative, propane) price declines that occurred during the 2008–2009 recession. Given the sensitivity of propane costs to delivery distances, propane fleets are most cost effective when they are situated near major natural gas liquid pipelines and the large, pressurized aboveground storage tanks located at approximately 25,000 retail propane dealers nationwide. The pipelines, in particular, can maintain high deliverability during peak demand periods, thereby helping to mitigate price spikes.

An opportunity exists for Clean Cities to work in partnership with PERC and the existing network of 25,000 retail propane dealers. Such a partnership could serve to educate the dealers about the use of propane as a vehicular fuel and encourage them to promote the product to potential fleet customers.

New Product Availability and the Cost of Vehicles and Infrastructure—The recent introduction of new generation propane vehicles, which use LPI™ systems, and other assumptions made by ICFI, are expected to contribute to a near-term increase in propane sales. (Sloan and Meyer, 2009). The ICFI Report suggests an increase in the on-road vehicle sector of between 10–15% per year from 2012–2020. However, this projection includes the soon-to-be discontinued school bus and the Cummins Westport engine. If we assume that new products take their place, such as the ESI engine and a new partner for the school bus, then these figures could be representative. However, these percentages may be delayed because of the research and development of the new engines and the subsequent certification process.

The U.S. propane industry could benefit from the development of a LPG hybrid vehicle. Examples exist in international markets, where propane hybrids offer advantages in emissions and fuel economy. The Avante LPI™, which is sold in the Korean market and manufactured by Hyundai, runs at 17.8 kilometers per liter, or equivalent to 37 mpg, but it costs 40% less than the competing Honda Civic Hybrid (Deok-hyun, 2009). Another source claims that the vehicle attains even better fuel economy at 41.9 mpg (Green Car Advisor, 2009a). Kia has released a similar LPG hybrid in South Korea that reportedly attains 42 mpg. This vehicle is an LPG-electric hybrid version of the Forte sedan. Kia hopes to sell 2,000 units in 2009 and 5,000 in 2010. In South Korea, propane is sold at less than half the cost of gasoline (Green Car Advisor, 2009b).

In regard to price, should a heavy-duty engine be developed for propane, an opportunity exists because of the upcoming 2010 heavy-duty emission standards. Heavy-duty diesels will require similar engine and after-treatment upgrades. There will be costs for compliance, thereby offering an opportunity for the propane industry. As recently as August 6, 2009, Daimler Trucks North America announced an additional price point of $9,000 for the Detroit Diesel® BlueTec™ technology, which is necessary for compliance with the 2010 emissions regulations. Furthermore, a surcharge of $7,300 will be added to vehicles equipped with the Cummins ISC 8.3-L engine, and a $6,700 surcharge will be added to the price of vehicles equipped with the Cummins ISB 6.7-L engine. Daimler Trucks states “that the surcharges reflect costs associated with adding selective catalytic reduction, which has been proven to significantly improve fuel economy compared with EPA 2007 engines, while reducing long-term operating costs and meeting the stringent, near-zero emission standards set by the U.S. Environmental Protection Agency (EPA) that take effect January 1, 2010” (Daimler Trucks NA, 2009).

The cost of propane infrastructure is reasonable, with a range from $25,000 to $175,000, depending on the station design. Federal and state tax credits can help deflect some of these costs.

Niche Markets—One optimistic source for future use of propane in transport is the 2007 California State Alternative Fuels Plan. This source (CEC, 2007, Table 4, p. 41) estimates a maximum amount of alternative fuels in 2022; of this total, about 5% is propane (CEC, 2007). This report encourages fleet and market niche purchases of propane vehicles, so we have examined some potential markets where propane could succeed with a concerted effort. We decided to examine the following markets: school buses, taxicabs, police, and paratransit vehicles. The California Energy Commission (CEC) report includes scenarios to 2050, one of which includes a very significant penetration of natural gas (36%) in heavy-duty transport. Propane does not make this type of penetration. However, we decided to look at the petroleum reduction benefits if propane could make that same penetration in certain niches.

By applying a 36% penetration by 2030 to EIA projections of U.S. school-bus energy consumption (EIA data project only to 2030 and not to 2050), with use of the GREET model (assuming 70% natural gas and 30% petroleum for the LPG feedstock), a reduction of approximately 16,000 barrels of oil per day could be achieved. We did not have future projections for the other markets, so we are assuming no growth from the data we have.

In 2005, according to the Bureau of Transportation Statistics (BTS), there were 162,000 taxicabs. According to the AFDC, these vehicles, on average, travel between 60,000–80,000 miles (we use 70,000 miles) per year (EERE, 1998). We do not have fuel economy data for this fleet; although we know that they are often driven in dense traffic. We assume 17 miles per gallon, which is close to the U.S. average fuel economy (BTS, 2009b). Applying a 36% penetration to this fleet would result in a reduction of approximately 10,000 barrels of oil per day.

In 2005, according to the BTS, there were 412,000 police vehicles. We do not have reliable mileage or fuel economy data, but anecdotal evidence shows that these vehicles are driven significantly more than the average passenger vehicle (Indy.com, 2009; Schmechel, 2009; and Sheriff, 2008). We assume that they would be driven 30,000 miles per year and have a fuel economy of 17 miles per gallon. Applying a 36% penetration to this fleet would result in a reduction of approximately 10,000 barrels of oil per day. .

Applying a 36% penetration to the paratransit fuel use reported by APTA, for 2007, would result in a reduction of approximately 2,000 barrels of oil per day (APTA, 2009).

Tax Credits Extensions—As with the natural gas vehicle industry, the tax credits discussed earlier provide a significant incentive to fleet users to purchase propane vehicles, invest in the refueling, and give manufacturers the confidence that they will have future markets in which to sell their products. The major issue is long-term availability. Since the credits for fuel, vehicles, and infrastructure are set to expire in the 2009–2010 timeframe, extensions will be necessary to provide assurances to industry and fleet customers and to justify long-term investments in vehicle research and development and propane fleet purchases. If they are not extended, this issue appears to be a significant barrier to future deployment.

Increased Interest in Transportation Propane by Fuel Distributors—According to the ICFI Report, the biggest challenge facing the propane industry during the next 10 years could be maintaining the current market share in the residential and commercial sectors, which account for 70% of the total odorized propane demand. Propane is expected to see a decline in fuel use in several areas, including the manufactured housing sector and the home heating and commercial space heating markets, since the electric heat pump and geothermal heat pump products are becoming more competitive. If these markets do erode, fuel distributors may decide to promote aggressively propane as a transportation fuel. In addition, one association has observed a generational shift in attitude, leading to greater responsiveness to the use of propane in the transportation sector. Having additional interested parties could only help the transportation sector.

***Rebate Program for Low-Emission Refueling Equipment*—**In partnership with industry and the states, a national rebate program to exchange the existing valves and nozzles of low-emission equipment would be viewed as a proactive step before possible regulations are adopted to reduce fugitive emissions. The Western Propane Gas Association is successfully operating such a program and could serve as a model. This rebate funding is allowed for up to 75% of the purchase price of the new equipment; funding will be exhausted at the end of 2009 (Brown Garland, 2009). In total, 1,600 pieces of low-emission equipment from major distribution points to retrofitting tanks with low-emission outage valves have been installed. Through 2009, $350,000 was expended for this program. As an initial step, an analysis should be conducted to determine if this is a significant issue for the rest of the country.

***Clean Cities*—**In the 15-year history of the Clean Cities program, the propane industry has partnered with the Clean Cities network to assist with the deployment of vehicles, the construction of infrastructure, and the outreach to fleets and the public. In addition to being upcoming partners in the *Adoption Market Strategy* and currently participating in the propane road shows, some possible near-term opportunities include:

1) ***Renewing Emphasis on Key Markets: School Buses, Taxicabs, Police, and Paratransit***—Similar to the opportunities detailed in the Natural Gas Vehicle Paper, the Program could develop new tools for fleet managers in those targeted niches and for fuel distributors, including materials that address:

- Supply of propane;
- Results from new testing of emissions and durability;
- Product offerings that meet 2010 emission standards;
- Fuel economy and performance;
- Safety concerns for fleets and the OPD overfill issue;
- Pay-back period for the total investment by a fleet, including the initial vehicle cost and operating costs (i.e., fuel, maintenance, product longevity, insurance rates, and resale value)

2) ***Focusing on Rural Markets***—Some coalitions whose base extends beyond its major metropolitan area may want to approach smaller cities with propane vehicle options, such as paratransit vehicles, school buses, taxis, police cars, and forklifts and trucks located in manufacturing facilities. An analysis could examine where the 25,000 propane fuel distributors are located, the population size of the community, and whether the community is located within the Clean Cities coalition jurisdiction. This effort would define some new opportunities in smaller markets for certain Clean Cities.

3) ***Partnering with Targeted Niche Market Associations—*** While Clean Cities has over time participated in relevant trade shows and placed articles in association newsletters, there may be better opportunities that could be defined by renewing contact directly with key associations, such as Taxicab, Limousine, and Paratransit Association, National School Transportation Association, and National Association for Pupil Transportation. The new tools developed above would be of interest to many of their members. In addition, training courses specifically on propane could be offered, with topics on how to build an alternative fuel fleet, safety, maintenance and driver training.

4) ***Cooperating with State Propane Associations***—While some state propane associations are not greatly interested in the transportation market, there may be ways to engage them, such as partnering in efforts to train fire marshals about permitting and to educate fleets on OPD inspection and overfill issues. Additionally, if the propane school bus market is able to find another engine partner to manufacture an LPI engine, an opportunity should be explored to determine those schools in each state that heat with propane. Subsequently, an outreach program could be developed that would discuss the benefits of adding a fleet of propane school buses (Brown Garland, 2009). Such an effort may help to meet the needs of the state propane associations that favor commercial heating propane markets over transportation markets.

5) ***Examining Market-Based Trading of Carbon Emissions for Propane Vehicle Projects to Encourage Investment in Alternative Fuel Fleet Projects*—**Clean Cities coordinators and stakeholders appear to be interested in measuring the carbon benefits of propane and other AFVs and using the reductions for the purpose of meeting future carbon legislation goals and other voluntary efforts.

6) ***Developing a Corporate Imaging Program*—**Clean Cities could develop a Corporate Imaging Program that includes issuing awards to fleets that make significant purchases. This Corporate Imaging Program could be promoted to national media outlets.

Conclusions

A sufficient supply of propane to fuel-targeted fleet vehicles appears to be available, with opportunities in the school bus, taxicab, police, and paratransit markets. While a 36% penetration rate is a high case scenario, it is a long-term goal that could be reached if challenges are overcome and new strategies are adopted. Furthermore, although the authors of this paper did not delve into the opportunities in the general consumer markets, propane fuel could be adopted by public consumers, as it has been in other European and Asian markets. However, the cost differential would need to be overcome and many more vehicle options would be needed. Infrastructure is relatively inexpensive to build, and a good network of 25,000 propane fuel distributors exists, thereby offering a very good foundation for opportunity.

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